A Review of Fabric Identification Based on Image Analysis Technology

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Abstract

This paper provides a review of the automatic methods used for the identification of woven fabrics developed in nearly 30 years starting from the mid-1980s until now. Compared with the manual method based on human eyes and experiences, the objective evaluation technology based on image processing and artificial intelligence holds the advantages of quick response, digital solution and accuracy. This paper describes briefly the background of weave pattern recognition and its development based on an overview of many researches done before. The reported methods can be classified into five categories (diffraction analysis-based, photoelectric analysis-based, frequency domain analysis-based, spatial domain analysis-based, jointed methods and other ones). Both the merits and demerits of frequency domain analysis-based and spatial domain analysis-based methods have been summarized and discussed in this paper. Therefore, it can provide a good reference platform for the researchers to understand and utilize these methods presented for the recognition of woven fabric weave pattern.

Keywords

Woven Fabric; Pattern Recognition; Image Processing; Artificial Intelligence

Introduction

The weave pattern identification of woven fabrics at yarn level is traditionally subjective and manually operated in the textile laboratory based on human eyes with the aid of pins, although it has been considered as one important and essential step before the fabric manufacturing. This method is not only of low efficiency and time consuming, but also subjectively affected by the knowledge and experiences of inspectors (Xu et al., 2005). Therefore, many researchers have committed to the use of image processing technology to identify the weave pattern automatically, in order to improve the efficiency of textile production.

Since the mid-1980s, a large number of papers focused on weave pattern recognition have been reported. Generally, the research publications can be divided into three regions: 1) Japan starts the related works from the very beginning in the mid-1980s; 2) then, it is followed by the Europe and America, from 1990s to 2000s; 3) the researchers in China and Asia region continues from the 2000s till now. Obviously, this phenomenon corresponds to the shifting of world textile manufacturing center from Europe and America to China. The major contribution of digital solution to weave pattern recognition is automation and labor saving.

Among these papers, some researchers concentrated on the exploration of the device of fabric image acquisition, while other researchers did some researches on the algorithm development for the weave pattern analysis. In general, these methods can be categorized into two groups according to the way of information acquisition: 1. Optical analysis-based that can be further classified into two groups: 1) Diffraction analysis-based; 2) Photoelectric analysis-based; 2. Image analysis-based that can be further classified into three groups as well: 1) Frequency domain analysis-based; 2) Spatial domain analysis-based; 3) Jointed methods and other means as depicted in FIG.1

Research Methods

In the mid-1980s, Japanese researchers firstly proposed a method for structure recognition and yarn density measurement based on the diffraction images and digital image processing technology. Then, the photoelectric and image based methods were widely adopted for the textile inspection.

Diffraction Analysis Based

Using the optical components of the diffraction image for the structural recognition of woven fabrics was firstly proposed by Ryuichi, 1986. The size and spacing of the highlights of those negatives can be measured based on the diffraction image of fabrics, then the weave pattern can be recognized by the calculation on its structure functions. The relationship between the

weave diagram and its diffraction pattern established using digital image processing technology, was suitable for the identification of plain, twill, satin and derivative fabrics (Kinoshita, 1989).

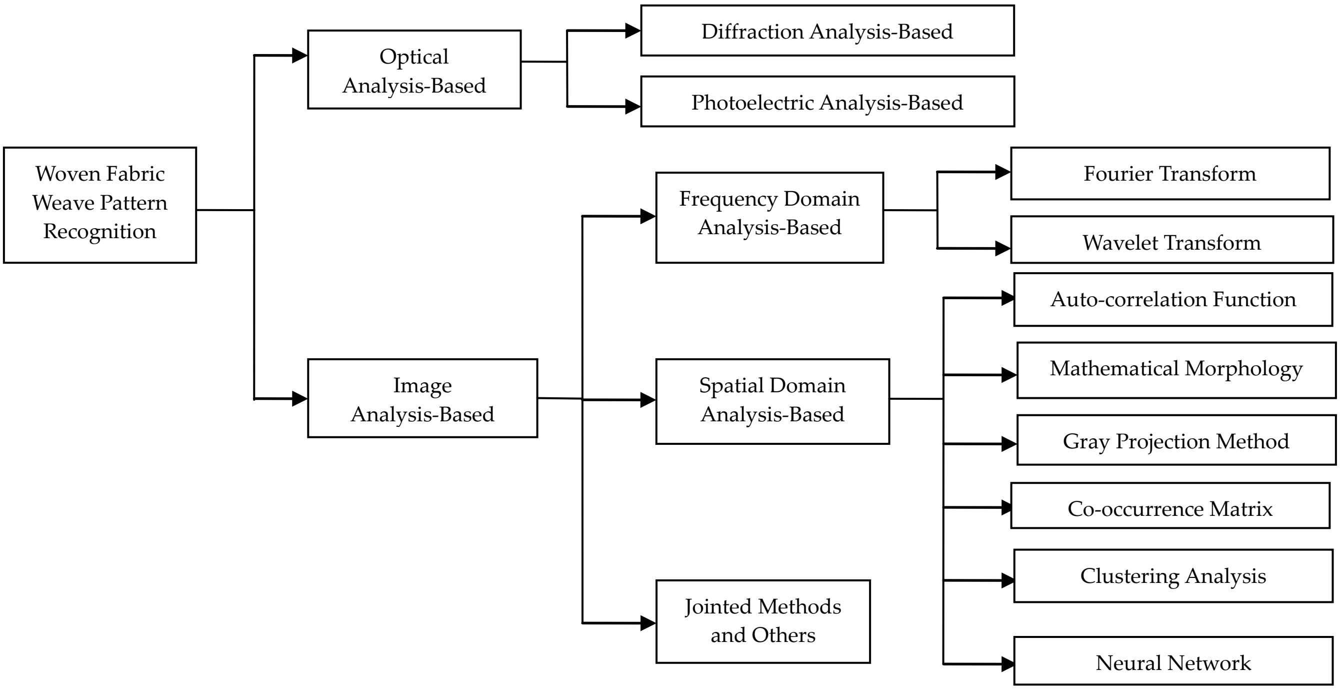


FIG. 1 DIFFERENT APPROACHES FOR THE WEAVE PATTERN RECOGNITION

Photoelectric Analysis Based

Zhong et al., 1996 presented the optical and electric system used for the fabric analysis as illustrated in FIG.2 and it was designed to convert the fabric image into high contrast fringes through some space filters which can be reflected onto the Charge-coupled Device (CCD) and converted the optical signal into electrical signal based on photoelectric effect. After processed by the amplifying, filtering and differential circuit, the number of bright and dark lines within the unit intervals can be measured by a single chip microcomputer. This apparatus was developed for the measurement of fabric density with the advantages of on line testing, in addition, the system accuracy was reported to be $\Delta N<1$.

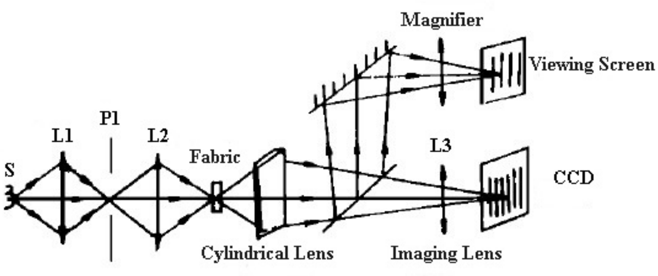


FIG. 2 OPTICAL DIAGRAM OF THE PROPOSED PHOTOELECTRIC ANALYSIS SYSTEM

Frequency Domain Analysis Based

The Fraunhofer diffraction-based method considered to be similar to the Fourier transform technology in the principle, can be used for the weave pattern recognition. Therefore, some researchers attempted to use the Fourier transform to recognize the weave pattern in the frequency domain.

1) Fourier Transform

Fourier transform (FIG.4) and grating method were first presented to process the fabric image and estimate its weave pattern by Imaoka, 1988; Inui, 1992. It was reported that the overall accuracy of this method could be as much as over 80%. Wood, 1990 also employed Fourier transform and auto-correlation function to model the spatial periodicity of fabric pattern, and a series of features was defined based on the two-dimensional power spectrum and two-dimensional auto-correlation diagram. Sari-Sarraf, 1996 developed one set of digital system used for the online detection of fabric density, composed of a linear array CCD, a frame grabber and a computer; thus, the real-time Fourier transform can be computed with the aid of digital signal processing (DSP), then the frequency information of weave pattern can be extracted from the annular distribution curve of power spectrum.

It was reported that the accuracy of the measurement can reach less than 2 yarns per inch. Besides, Xu, 1996 utilized the Fast Fourier transform (FFT) to calculate the power spectrum of fabric image and employed the logarithm operation to compress the power spectrum to achieve spectrum gray image. The origin point of the power spectrum can be relocated in the center of fabric image with the aid of the coordinate transformation. Then, Xu determined the peaks of power spectrum in different directions corresponding to the regular and periodic structure and extracted the frequency of these periodic structures along both the vertical and horizontal directions separately. Finally, both the warp images and weft images can be reconstructed based on the filtered power spectrum only keeping the peak points and the relationship model between the weave pattern and its power spectrum could be established as depicted in FIG.3. Similar methods have been extended and widely applied in many references. (Ravandi & Toriumi, 1995; Xin et al., 1999; Escofet et al., 2001; Rallo et al., 2003; Lachkar et al., 2005; Tunák et al., 2010; Pan et al., 2011).

2) *Wavelet Transform*

An adaptive wavelet transform-based method (Feng & Li, 2001) was employed to perform a multi-scale decomposition and measure the woven fabric density. Firstly, the horizontal and vertical high frequency sub-images were generated by a standard decomposition at a selected direction and scale, which contain the warp and weft information separately as shown in FIG.5; then, the fabric density and the related structural features could be analyzed using the simple thresholding, filtering and frequency analysis (Li et al., 2005) as illustrated in FIG.6. It was noted that the error of this automatic detection method was less than 3% compared with the manual operation.

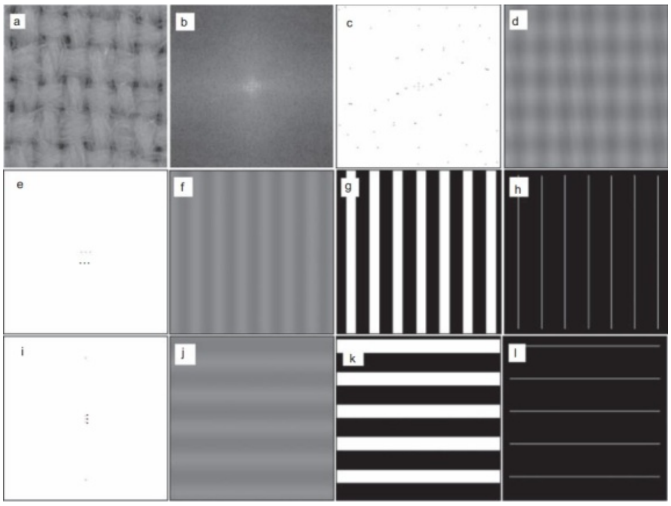


FIG. 3 IMAGE (a) IS A PLAIN WOVEN FABRIC; IMAGE (b) IS POWER SPECTRUM; IMAGE (c) KEEPS ALL THE PRINCIPAL PEAKS IN THE POWER SPECTRUM ONLY, AND IMAGE (d) IS ITS RECONSTRUCTED IMAGE (c); IMAGE (e, f, g, h) PRESENT HORIZONTAL SELECTED PEAKS, WARP IMAGE (f), THE BINARY IMAGE OF IMAGE AND THE THINNED IMAGE OF IMAGE (g) RESPECTIVELY; IMAGE (i, j, k, l) PRESENT THE VERTICAL SELECTED PEAKS, WEFT IMAGE, THE BINARY IMAGE OF IMAGE (j) AND THE THINNED IMAGE OF IMAGE (k) RESPECTIVELY.

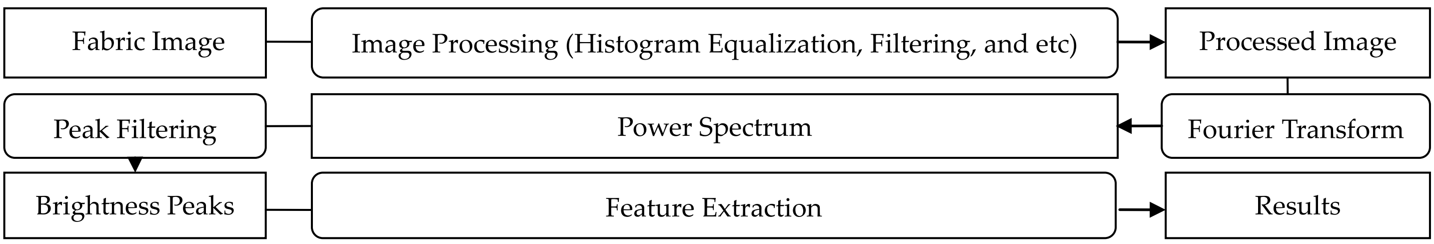
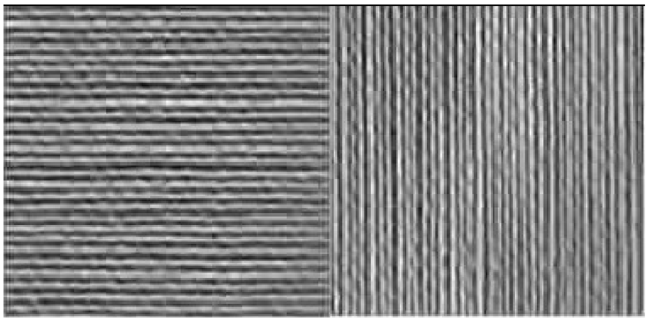


FIG. 4 FLOWCHART OF THE FOURIER TRANSFORM BASED METHODS

Shen et al., 2007 recommended a novel approach for fabric weave pattern and structural pattern detection. Wavelet and Radon transform suitable for fabric image signal decomposition and fabric texture line detection, respectively, were combined together to detect fabric texture directions, recognize weave patterns and measure yarn densities. Recently, a two-dimensional fabric textures identification algorithm based on

discrete wavelet transform was proposed by Liu, 2012. The different levels and direction component organization points of graphic images were mapped and the benchmark position of the two-dimensional images was estimated. Then, discrete wavelet transform was utilized to extract two-dimensional texture parameters and cluster the texture parameters.



(A) HORIZONTAL IMAGE (B) VERTICAL IMAGE

FIG. 5 SUB-IMAGES DECOMPOSED BY ADAPTIVE WAVELET

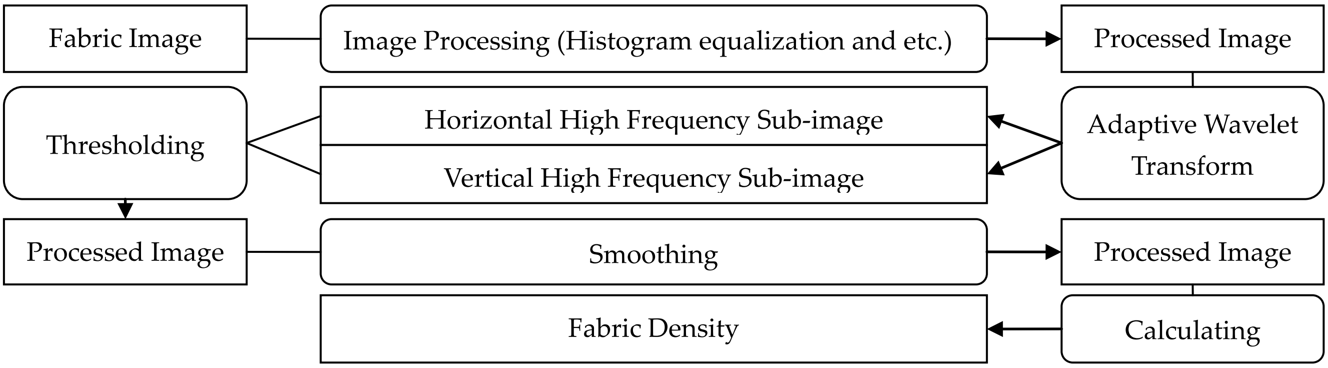


FIG. 6 FLOWCHART OF WAVELET TRANSFORM BASED METHOD

Spatial Domain Analysis Based

Sometimes, it is difficult to classify the interlaced warps and wefts, even though the frequency domain analysis-based methods can recognize the periodic structure of woven fabrics efficiently. Therefore, some researchers attempt to apply the spatial domain analysis-based methods for the weave pattern recognition.

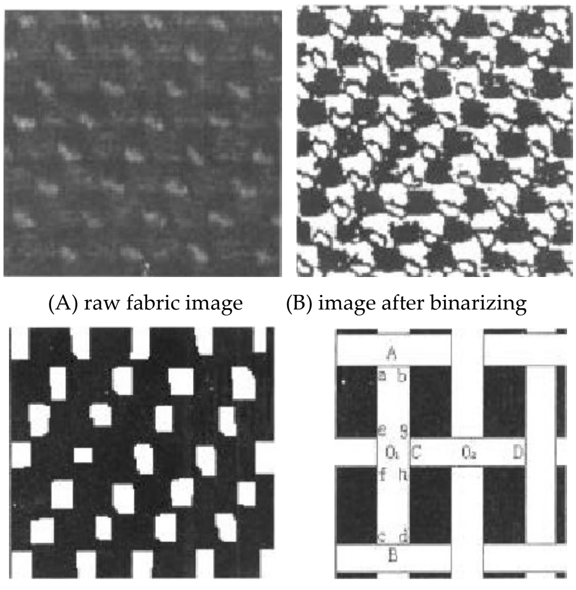
1) *Auto-correlation Function*

The correlation function-based approach was used to calculate the weft and warp repeats by Gao et al., 2002. The position and the density of warps can be determined through the binarization and medium filtering. Meanwhile, the number of warps in the repeats unit can be calculated based on the least common multiple of the minimum warp repeats of each weft unit. Finally, the characteristics of weft unit interlacing points can be identified. Recently, a new method based on the skew rectification and histogram equalization was presented by Pan et al., 2010 for the pre-processing of the reflective images of woven fabrics. Then, the interlaced points can be located in the image by the gray projection curves of warp and weft. They can determine the warp and weft repeats according to the correlation of the interlaced points along the warp and weft directions. Finally, the types of interlacing points can be estimated by comparison of the average gray value of interlaced points in a weave repeat. It was revealed that the three basic weaves can be identified correctly using this approach.

2) *Mathematical Morphology*

Mathematical morphology (FIG.8) has been applied for the topological operations such as edge enhancing, binarizing, smoothing, histogram equalizing, filtering, sharpening, dilation and erosion, which can integrated to extract some useful information for the geometric representation and description of regional shape. Nishimatsu, 1991 utilized a CCD camera and a frame grabber board to digitalize the image of fabric at 50x magnification. It was calculated that the recognition accuracy for plain fabrics was about 92.5%, while the accuracy for twill fabrics was only 79.1%. Kang et al., 1999 designed a digital imaging system using the digital camera and an illuminating system to digitalize the transmitted and reflected fabric images. Using the transmitted images, both the warp and weft interlaced points and the yarn count can be determined by analyzing its gray value changes along both the horizontal and vertical directions. Using the reflected images, the types of interlaced points can be identified by analyzing the

normalized aspect ratio of an ellipse-shaped image. Further, the total number of yarn colors and its configuration in the fabric can be determined. Besides, several typical image processing methods and systems combined with linear fitting technique were developed by Li et al., 2003. The processed images were illustrated in FIG.7. It was reported that the recognition was of high accuracy for the light colored fabrics with coarse yarn density or composed with single yarns. However, this method was not suitable for those dark colored fabrics with high yarn density or composed with multiple yarns or colored yarns.



(A) raw fabric image (B) image after binarizing

(C) image after erosion (D) image after linear fitting

FIG.7 PROCESSED IMAGES

Recently, Jia & Li, 2008 decomposed the fabric image into the vertical and horizontal directions sub-images to recognize fabric structures automatically based on Wiener filter (Shady et al., 2012). The warp and weft structural parameters can be estimated from the sub-images after binarization, and the fabric density can be calculated accordingly. Then, the types of the interlaced points can be defined by the gray level difference along vertical and horizontal directions, after the interlaced points were defined by the texture information extracted from the sub-images.

3) Gray Projection Curve

Huang et al., 2000; Huang and Liu, 2001 introduced the image processing technique to recognize the fabric weave pattern and measure the yarn twist angle. They computed the gray projection curves (FIG.9) by cumulating the gray values along both the horizontal and vertical directions. Hence, the yarn position and the corresponding interlaced points can be determined. Finally, the types of interlaced points can be estimated by analyzing the geometrical characteristics of yarns.

Pan & Gao, 2008; Pan et al., 2008; Pan et al., 2010 employed a scanner to get the high resolution fabric image by scanning along the vertical direction and put forward a specific image size to analyze the fabric image. Locating the yarn clearances was used to correctly rectify the skew of the complete fabric image. Then, the position of the yarn clearances in the processed image can be estimated by the brightness information and the projection curve of the reflect image from the fabric surface. Finally, the accurate average distance of the yarn clearance can be computed by checking the distance of the yarn clearances in turn and the fabric density can be calculated accordingly. It was reported that the results had a relative error of 7%. Besides, a novel technique was designed by Xie & Yu, 2008 to digitalize its image after the fabric sample was fixed using the mechanical alignment, the distortion can be eliminated to improve the accuracy of yarn density measurement and weave pattern recognition. It was investigated that the error was less than 2% compared with manual testing results.

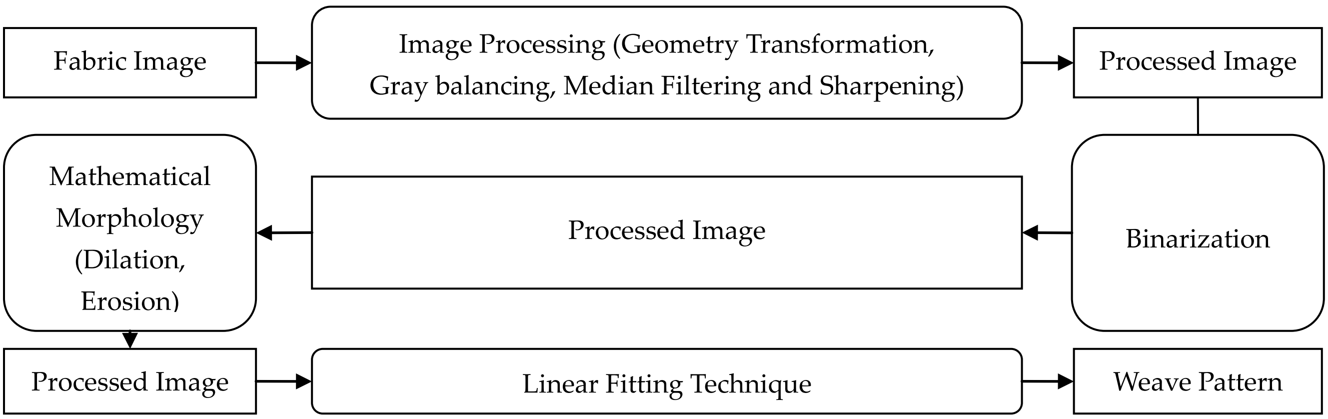


FIG. 8 FLOWCHART OF MATHEMATICAL MORPHOLOGY BASED METHOD

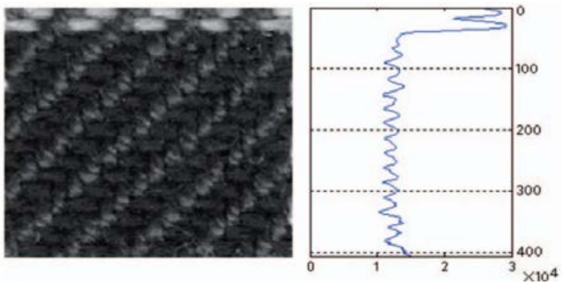


FIG.9 GRAY IMAGE AND PROJECTION CURVE OF THE FABRIC

Recently, a new method based on the active grid model(AGM) was first presented by Xin and Hu, and a double-face imaging system based on a panel scanner was designed to digitalize the double-side images as shown in FIG.10-11 (Xin et al., 2009). The initial yarn grid can be estimated by using the projection algorithm along both the warp and weft directions; then, the weave types of the yarn interlaced points were classified based on the edge map using a lookup table; after that, the estimated weave diagram result could be refined using the neighboring information of yarns. Meanwhile, the color configuration can be estimated using color clustering and matching. It was noted that the yarn–locating method can correctly detect the positions of 99.8% yarns and the color-information-based correction can reduce the error rate to 3.6%. The similar methods were presented based on digital camera and a rotating sample holder (Zhong et al., 2011; Zhong et al., 2013).

FIG. 10 UPPER-SIDE IMAGE FIG. 11 BOTTOM-SIDE IMAGE

4) *Co-occurrence Matrix*

Chang et al., 2008 applied a gray-level co-occurrence matrix (GLCM)-based approach to analyze the fabric textures. The image grayscales was first compressed from 256 to 16; and the computation cost of the algorithms can be reduced accordingly. Then, five GLCM parameters such as energy, contrast, correlation, entropy and inverse difference moment can be defined to describe the textile textures (Xin et al., 2012). It was reported that the GLCM-based algorithms can extract and analyze the textures of plain, twill and satin weaves efficiently. Another novel automatic method based on digital image analysis techniques was introduced by Wang et al., 2009; Wang et al., 2010. Their method is based on the integral projection in the spatial domain to identify the segments corresponding to the weft yarns and warp yarns; then, the detected segments were classified into two clusters based on unsupervised fuzzy c-means (FCM) clustering on multi-scale direction invariant texture features. Further, the yarn crossed-area states can be estimated automatically. It was estimated that over 95% of the yarn crossed-area states can be identified correctly.

5) *Clustering Analysis*

Chen, 2006 utilized a color scanner to digitalize the gray-level images of solid woven fabrics. The enhanced images were then obtained after a morphological operation and the warp and weft crossed areas can be located based on the interlacing points. Four texture types in these areas were featured using the first-order and the second-order statistics method and then classified by a fuzzy c-means (FCM) clustering method. The results were demonstrated that three basic weave patterns can be identified correctly. Similar methods have been reported and applied in the references (Kuo et al., 2004; Pan et al., 2010c). Besides, a new method based on the particle swam optimization algorithm for weave pattern recognition was presented by Chen & Tu, 2010. A USB digital microscope was used to capture the fabric images. After a series of image pre-processing, such as histogram equalization, binarization and denoising, the characteristics of the fabric construction can be extracted by the width method with warp weft, and the particle swam optimization was then used to identify the weave patterns.

6) *Neural Network*

Kuo et al., 2010 developed a weave pattern identification system. The warp and weft can be identified by the pixel gray-level cumulative values. The value of the defined texture features can be calculated and the yarn interlacing type can be estimated by fuzzy c-means (FCM) algorithm. Then, the weave diagram and matrix of the woven fabrics can be derived based on the two-stage

Back-Propagation Neural Network (Pan et al., 2011).

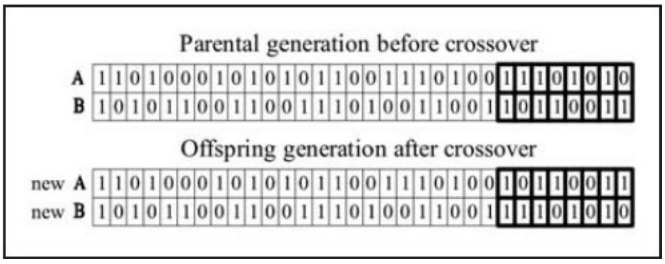


FIG.12 SINGLE-POINT CROSSOVER

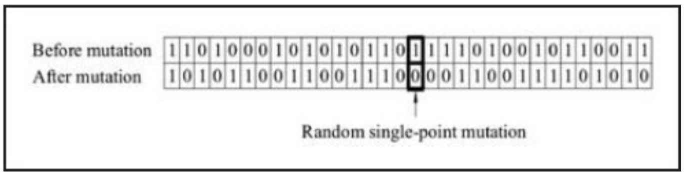


FIG.13 RANDOM SINGLE-POINT MUTATION

Pan et al., 2011 proposed a novel method based on a genetic algorithm (GA) to recognize the layout of color yarns of yarn-dyed fabric from the color pattern. The principle of a genetic algorithm was interpreted, and then the layout of color yarns was correctly recognized by the crossover (FIG.12) and mutation (FIG.13) operation to the chromosomes, which represent the information of the layout of warps and wefts. It was reported that the method had the fault-tolerance ability to some degree. Similar methods have been widely applied in many references (Luo, 2011; Zhang et al., 2011; Kuo et al., 2011; Kuo et al., 2012).

Recently, Jing et al., 2011 achieved the sub-images by using the two-dimensional wavelet transform in order to speed up the system running time. Then, the feature parameters of the gray level co- occurrence matrix can be extracted from the sub-images. Finally, they employed the learning vector quantization neural network to identify and classify the woven fabric structures. Lim & Kim, 2011 developed an integrated hardware and software system (FIG.15-16) to recognize the construction of woven fabrics automatically. The ultra-high resolution fabric images can be obtained with the aid of the dedicated hardware system. A series of image analysis techniques was applied to locate the interlaced points of warps and wefts. An artificial neural network (FIG.14) was constructed using two shape parameters extracted from those images as input and weave pattern as output.

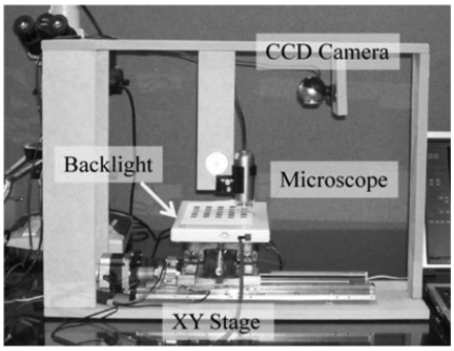


FIG.15 IMAGE ACQUISITION SYSTEM

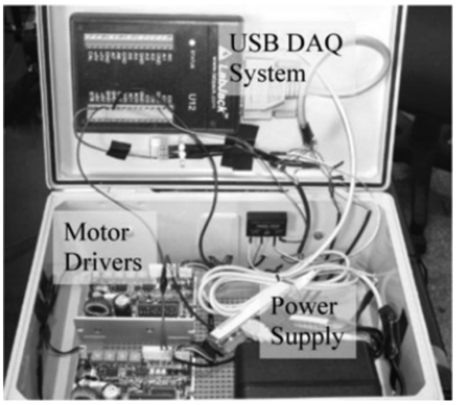


FIG.16 CONTROLLOR UNIT

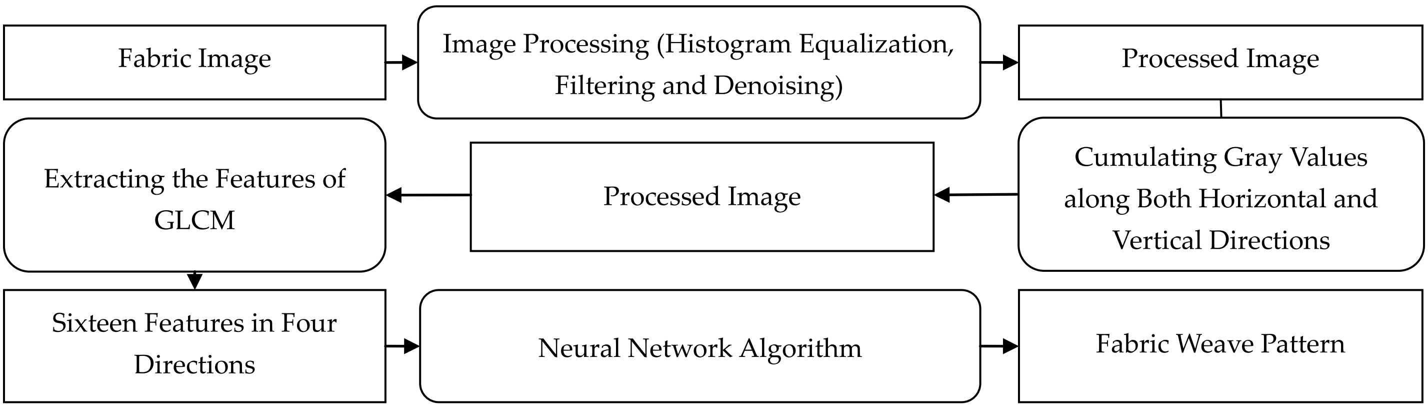


FIG.14 FLOWCHART OF NEURAL NETWORK BASED METHOD

Jointed Methods and Others

A video system image processing (VSIP) based approach was presented by Dusek, 1991 to measure woven fabric and knitted fabric yarn density, including one or multiple digital cameras consisting of high-resolution CCD arrays, a computer and a printer. Yurgartis et al., 1993 employed the computer-aided image processing techniques to quantify the yarn shape and the fiber orientation in microstructure level. It was revealed that the statistical variability of the sinusoidal descriptions of the yarn shape may be inaccurate; conversely, the yarn shape can change significantly during the laminate processing. The binarization image was obtained by using the rectangular type band pass filter, both the interlaced type and density of the warp and weft yarns can be identified accordingly (Ohta et al., 1995). Besides, Ren et al., 2009 utilized a special way to define a support vector and represent the weave pattern. Then, the sequential minimal optimization (SMO) algorithm can be applied to recognize and classify the weave pattern. Therefore, the weave diagram of the woven fabric samples could be reconstructed, which can facilitate the production and processing of woven products. Traditional image processing methods are all 2-D image-based, while the construction of woven fabrics is 3D, so 3D image-based method should have the advantages of accuracy compared to 2D image-based method. A novel method to extract the yarn positional information by using the X-ray computed tomography technology was presented by Shinohara et al., 2010 and a computerized program was developed to make the 3D re-visualization of the corresponding woven fabric structures (Potiyaraj et al., 2010).

Conclusions

Throughout the above reference review, these research methods can be divided into two major categories. The advantages and disadvantages of the two main methods are depicted in table1 and table 2.

The frequency domain analysis-based methods seems to be difficult to recognize the weave pattern of derivative weaves, jacquard organizations or yarn dyed fabrics, though it's suitable for the recognition of fabrics which have a regular texture. Hence, researchers have been trying to utilize the spatial domain-based methods, convenient for the yarn locating and weave pattern recognition. In summary, both the spatial domain-based methods and frequency domain-based methods have its advantages and disadvantages, and the joint of these methods or new imaging technology should be developed with the aid of high robustness algorithms, especially for those fabrics with irregular texture or multi-colored fabrics.

TABLE 1 MERITS AND DEMERITS OF FREQUENCY DOMAIN ANALYSIS BASED METHODS

Methods	Advantages	Disadvantages
Fourier Transform	1. Employ the frequency domain to characterize the periodic structure; 2. The frequency spectrum is invariant to rescaling, translation and rotation;	1. Information in spatial domain lost; 2. The types of interlacing points cannot be determined in specified region; 3. Not suitable for the multicolored and textured fabrics;
Wavelet Transform	1 Provide multi-resolution of image; 2 Enable to focus on local details; 3 Obtain the horizontal and vertical sub-images;	1. The computational cost of Adaptive wavelet transform is high; 2. Not suitable for the multicolored and textured fabrics;

TABLE 2 MERITS AND DEMERITS OF SPATIAL DOMAIN ANALYSIS BASED METHODS

Methods	Advantages	Disadvantages
Auto-correlation Function	1 Suitable for the yarn location in a repetitive unit; 2 Suitable for the regularity analysis of the texture unit;	Difficult to analysis the fabrics with irregular texture;
Mathematical Morphology	1 Good description of texture and shapes;	Difficult to recognize the weave pattern of fabrics with complex pattern or high density;
Gray Projection Curve	1 Locate the warps and wefts accurately; 2 Divide the fabric image into regular regions;	Cannot recognize the weave pattern of fabrics with high density exactly;
Co-occurrence Matrix	1 Characterize the spatial relationship of pixels; 2 Describe the texture information	1 Complex computing process and cost, with a slow speed; 2 Some valuable information lost in the undirected distance
Clustering Analysis	1 Suitable for unsupervised classification 2 Achieve the best classification performance objective data by the iterative optimization algorithm	Not easy to determine the initial clustering center of the algorithm
Neural Network	1 Enable to give reasonable output 2 Has a good fault tolerance and flexibility	Need for a large number of training

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